Operation of a Triple GEM Detector with CsI Photocathode in Pure CF_4
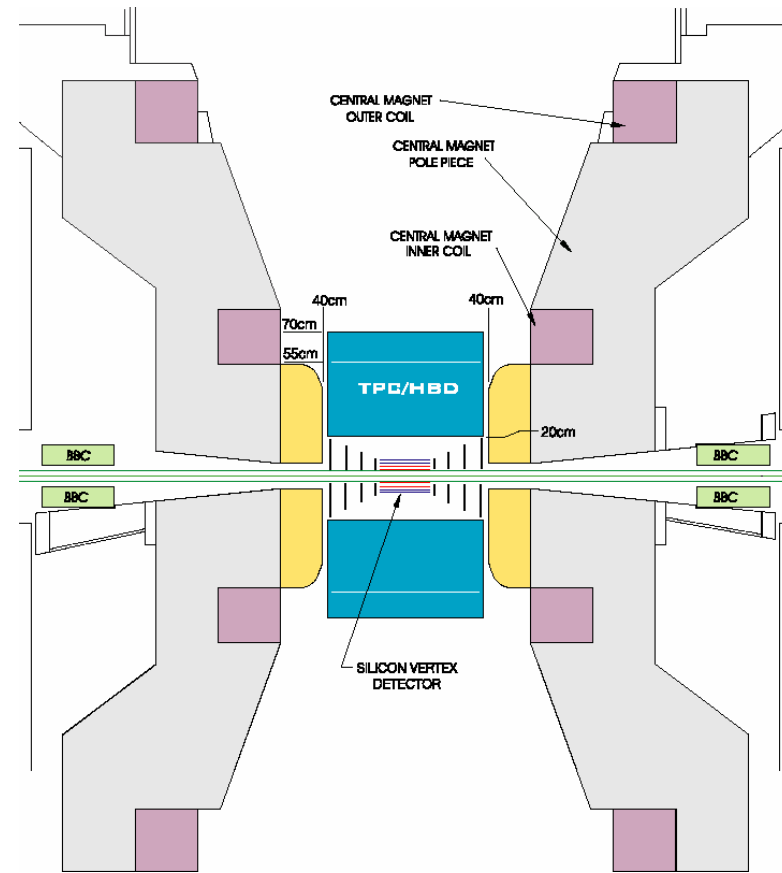
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Motivation

- A Hadron Blind Detector (HBD) is being considered for an upgrade of the PHENIX detector at RHIC

- HBD will allow the measurement of electron-positron pairs

- The primary choice is a windowless Cherenkov detector, operated in pure CF_4 in a special proximity configuration, with a reflective CsI photocathode and a triple GEM detector element with a pad readout

- Very large bandwidth (6-11.5 eV) and very high figure of merit $N_0=940$ cm^{-1}

- Approximately 40 detected photo-electrons in a 50 cm long radiator

CENTRAL MAGNET OUTER COIL

CENTRAL MAGNET POLE PIECE

CENTRAL MAGNET INNER COIL

40cm   40cm
70cm
55cm

TPC/HBD

20cm

BBC   BBC

BBC   BBC

SILICON VERTEX DETECTOR

Setup

- GEMs with 50 μm kapton thickness produced at CERN were used, two types: 3x3 and 10x10 cm^2

- Measurements with X-rays, α-particles and UV photons

- High voltage was supplied to GEM electrodes via a resistive chain

- Two gases for the measurements: CF_4 and Ar/CO_2 mixture (70/30%) for comparison

- All measurements were done at atmospheric pressure

- The system contained also devices for the precise measurement of T, P and water and oxygen content down to the ppm level
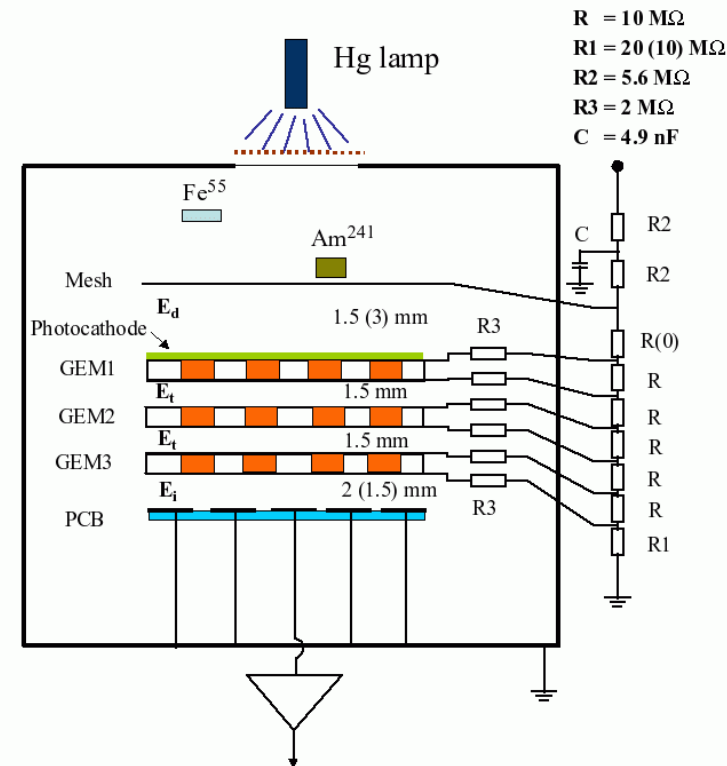
Measurements with X-rays:
pulse height spectra

- Fe^{55} 5.9 keV X-ray photons

- In both cases the pulse height spectra were measured at a gain higher than 10^4

- In Ar/CO_2 the main peak is very well separated from the escape peak and the energy resolution is ~22% FWHM

- For CF_4 measurements the energy resolution is close to 38% FWHM
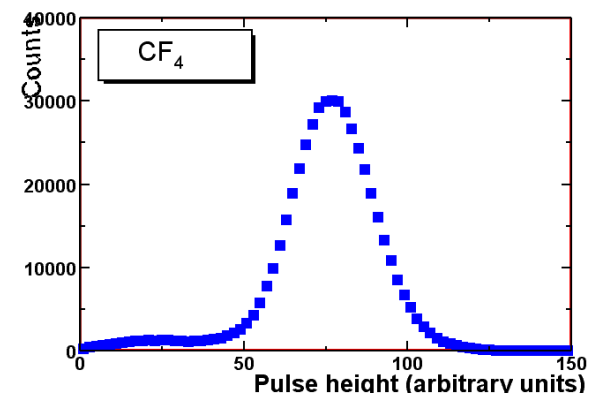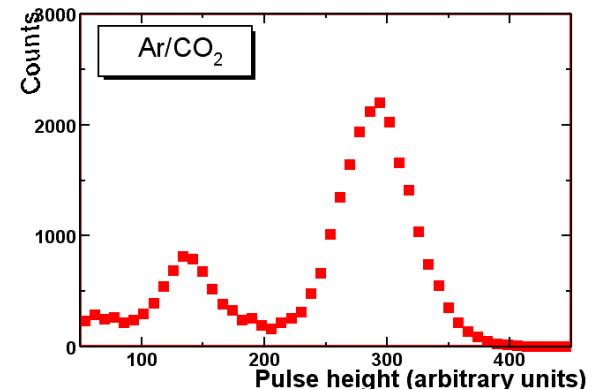
Measurements with X-rays:
gain as a function of GEM voltage

- Fe^{55} 5.9 keV X-ray photons
- All GEMs at the same voltages
- The absolute gas gain was determined from the measurements of the signal from Fe^{55} photons
- GEMs: 3x3 cm^2 and 10x10 cm^2
- Good reproducibility between the various sets was observed
- The slopes of the gain-voltage characteristics are similar for both gases but operational voltage for CF_4 is ~140 V higher
- The gain in CF_4 can reach 10^5
- Strong deviation from exponential growth at high gain
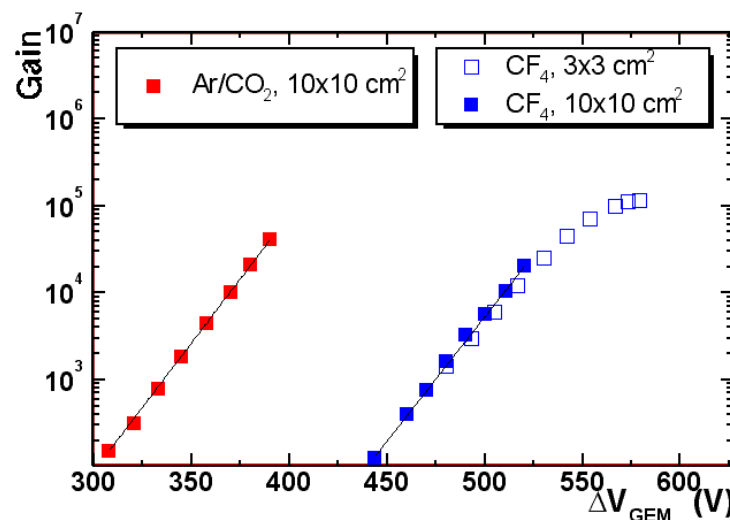
Sensitivity to the gas density

- The absolute value of the gain is very sensitive to the gas density

- Small variations of the gas pressure (P) and/or temperature (T) significantly affect the gain

- A change of 1% in P/T value causes a gain variation of 17% in Ar/CO_2 mixture and of 26% in pure CF_4
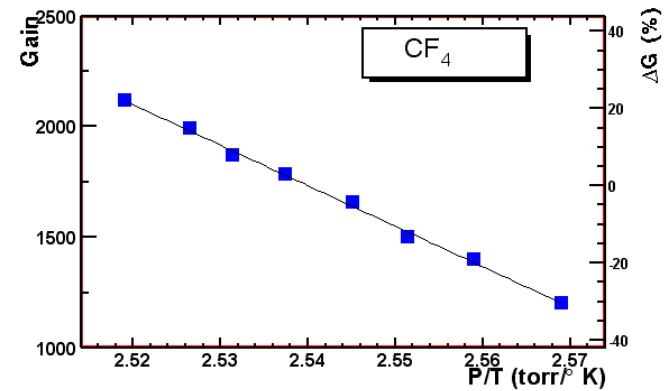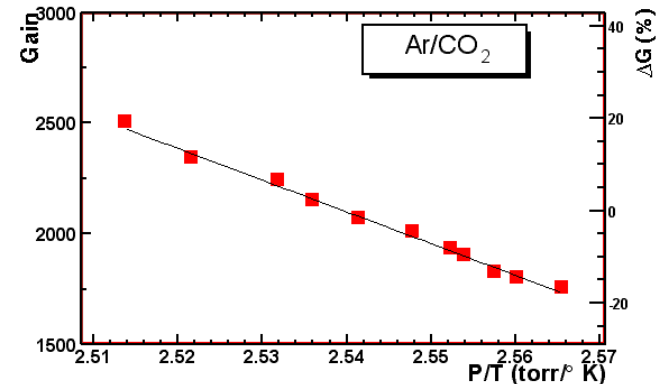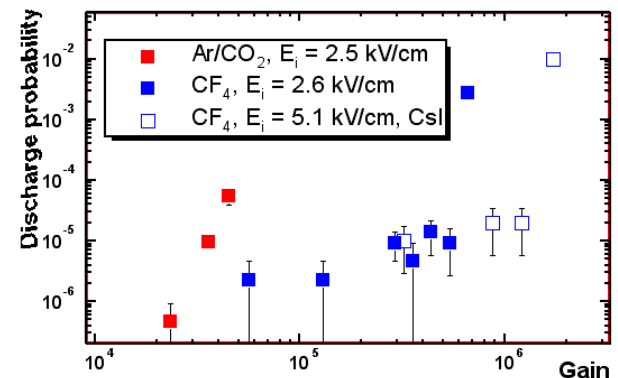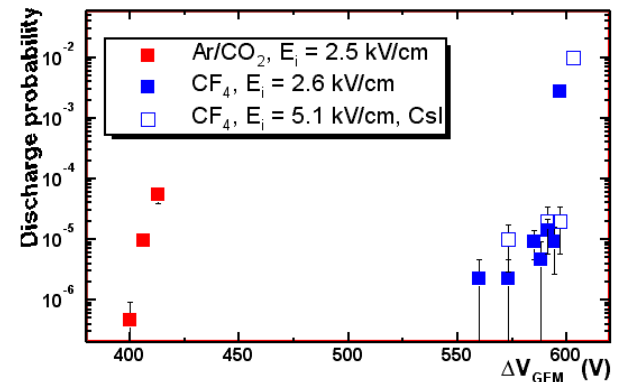
Measurements with α-particles:
total avalanche charge

- Am^{241} 5.5 MeV α-particles
- In the case of Ar/CO_2 mixture the charge depends on ΔV GEM exponentially, and the signal is saturated by the pre-amplifier
- In pure CF_4 the dependence of charge becomes non-linear above the value of $\sim 4 \times 10^6$ e and is completely saturated at $\sim 2 \times 10^7$ e, which is below the saturation level of the pre-amplifier
- The difference in performance may be due to the higher primary charge density and lower diffusion in CF_4
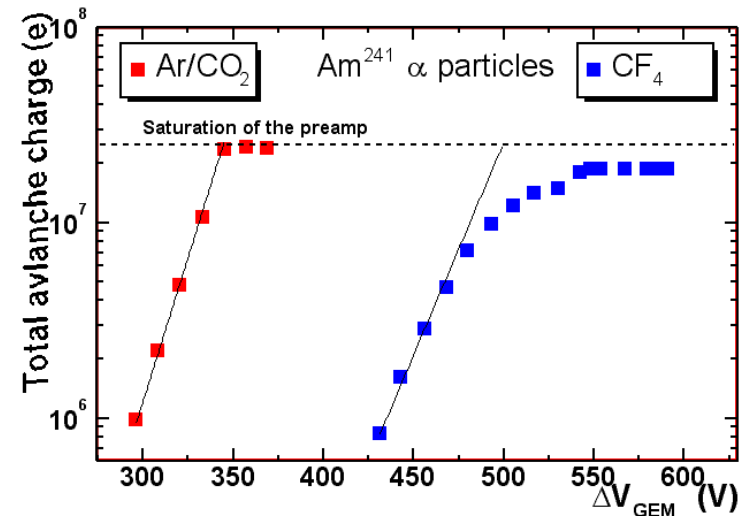
Measurements with α-particles: discharge probability

- Very crucial for the HBD
- The Am^{241} source was used to simulate heavily ionizing particles
- Definition of discharge probability: ratio between the number of discharges within a certain period of time and the number of α-particles traversing the detector during the same period
- For Ar/CO_2 rapid increase above 400V across the GEM, gain 3×10^4
- In CF_4 it grows above 590V, gain can reach extremely high values of close to 10^6
- HBD is expected to operate at gains $< 10^4$

Plot 1 — Discharge probability vs ΔV_{GEM} (V):
- Ar/CO_2, $E_i = 2.5$ kV/cm
- CF_4, $E_i = 2.6$ kV/cm
- CF_4, $E_i = 5.1$ kV/cm, CsI

Plot 2 — Discharge probability vs Gain:
- Ar/CO_2, $E_i = 2.5$ kV/cm
- CF_4, $E_i = 2.6$ kV/cm
- CF_4, $E_i = 5.1$ kV/cm, CsI

Measurements with UV photons: photoelectron current

- UV lamp as a source of UV photons
- Photocathode was prepared by evaporating 2000 A thick layer of CsI on the first GEM previously coated with thin layers of Ni and Au
- In order to determine the total emission from the photocathode without any amplification in the GEMs a positive (negative) voltage was applied between GEM1 and mesh
- The CsI photocathode was exposed to a total charge of ~7 mC/cm² - no sizable deterioration of the quantum efficiency
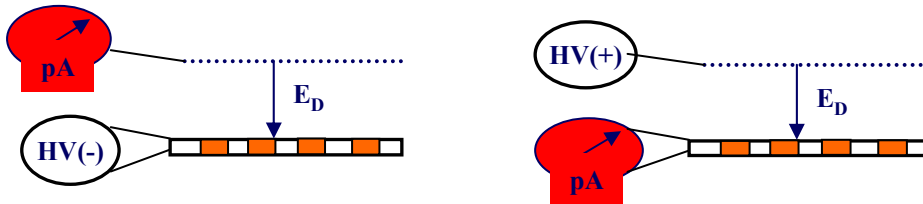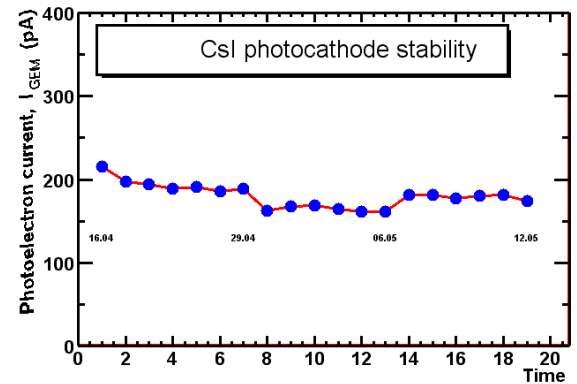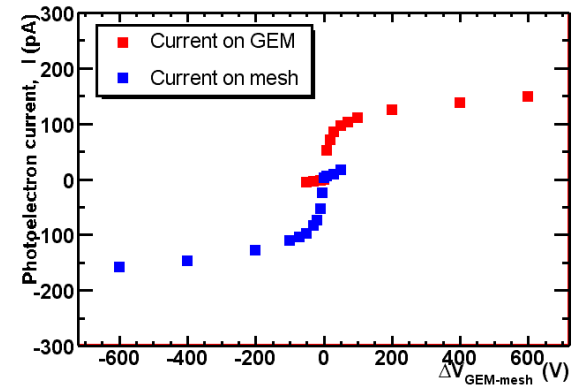
Measurements with UV photons:
gain as a function of GEM voltage

- UV lamp as a source of UV photons
- Clearly see two regions: an initial slow increase of current at lower voltages related to the increase of the extraction of the photoelectrons from the CsI surface into the holes of GEM1 and a steep exponential increase at higher voltages due to the amplification in the GEMs
- The electron extraction cannot exceed the maximum level shown on previous slide. It indeed seems to reach this level of 100%. Thus, the gain is determined as the ratio between the current to PCB and the extraction current.
- G^3 (single GEM) $\approx$ G (triple GEM)
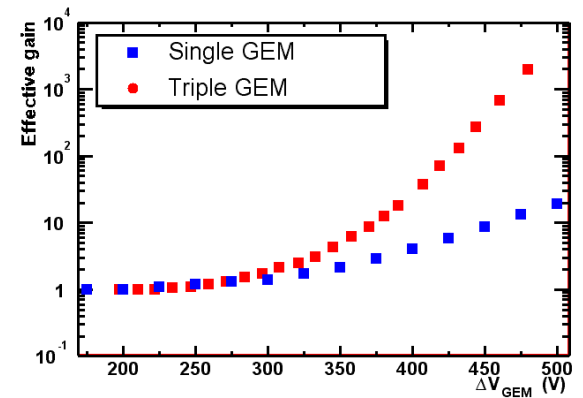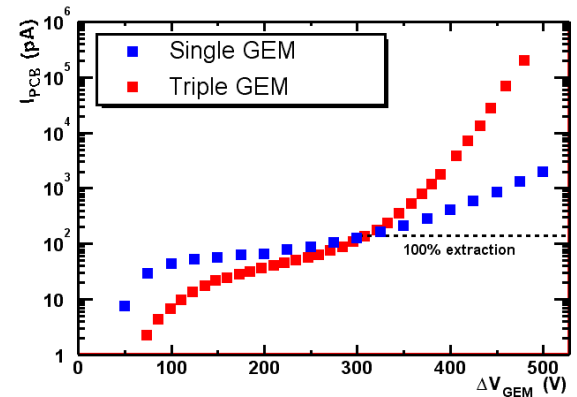
Measurements with UV photons:
ion back-flow

- UV lamp as a source of UV photons
- Definition of ion back-flow: ratio of the current to the photocathode and the current to the PCB
- No significant dependence of the ion back-flow factor on the nature of the gas is observed
- Neither variation in electrostatic conditions between nor inside the GEMs affect significantly the ion back-flow
- The only parameter which affects the value of the ion back-flow in our case is the induction filed E_i
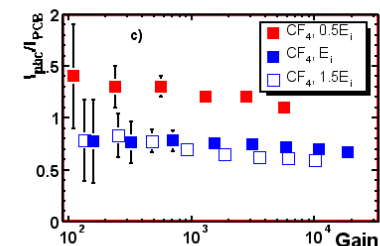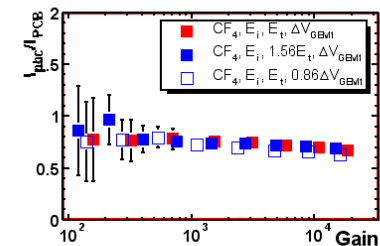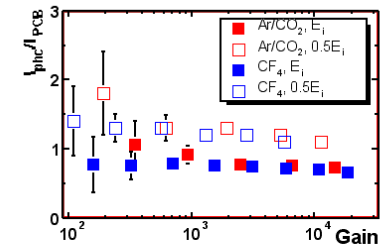
Summary

- Very encouraging results on the operation of a triple GEM detector in CF_4
- The slope of the gain curve is similar to that of conventional Ar/CO_2 (70/30%) gas mixture, however $\sim$140V higher voltage across the GEMs is needed for a given gain
- The gain curve starts deviating from exponential growth when the total charge in the detector exceeds $\sim 4\times 10^6$ e, and the gain is fully saturated when the total avalanche charge reaches $\sim 2\times 10^7$ e. This is an interesting property making the system more robust against discharges as compared to Ar/CO_2
- Stable operation can be achieved at gains up to 10^4 in the presence of heavily ionizing particles
- No deterioration of the GEM foil performance in a pure CF_4 atmosphere was observed for a total accumulated charge of $\sim$10 mC/cm^2 at the PCB
- The ion back-flow to the photocathode is close to $\sim$100%, independent of the operating gas and the transfer field E_t between successive GEMs. At a gain of 10^4, the ion back-flow can be reduced to $\sim$70% by applying a relatively high induction field of $E_i \sim 5$ kV/cm
- In spite of the high ion back-flow no sizable deterioration of the CsI quantum efficiency was observed when the photocathode was exposed to a total ion charge of $\sim$7 mC/cm^2. This value is larger by about two orders of magnitude than the total integrated ion charge expected during the lifetime of the planned HBD